Space Environment
TOPICS

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Navigation

Navigation, the science of finding one's way on Earth, has become ever more exacting as we endeavor to travel faster with more precision. In ancient times, the stars provided markers sufficient for a traveler to determine at least an approximate position. But as journeys moved upward from sea level, then far away from Earth's surface, the necessity for three-dimensional positioning was born.

For twentieth century travel, latitude, longitude, and altitude information in real time are necessary. To help meet more stringent requirements, radio-wave systems such as Loran-C and Omega were developed. These terrestrial-based systems use large transmitter antennas to send low-frequency (LF) and very-low-frequency (VLF) radio waves, along the ground and off the reflective layer provided by the ionosphere, to vast distances over land and sea (see Figure 1). The ionosphere is formed by ultraviolet radiation from the Sun impinging on the upper atmosphere and photo-ionizing the atmospheric constituents.

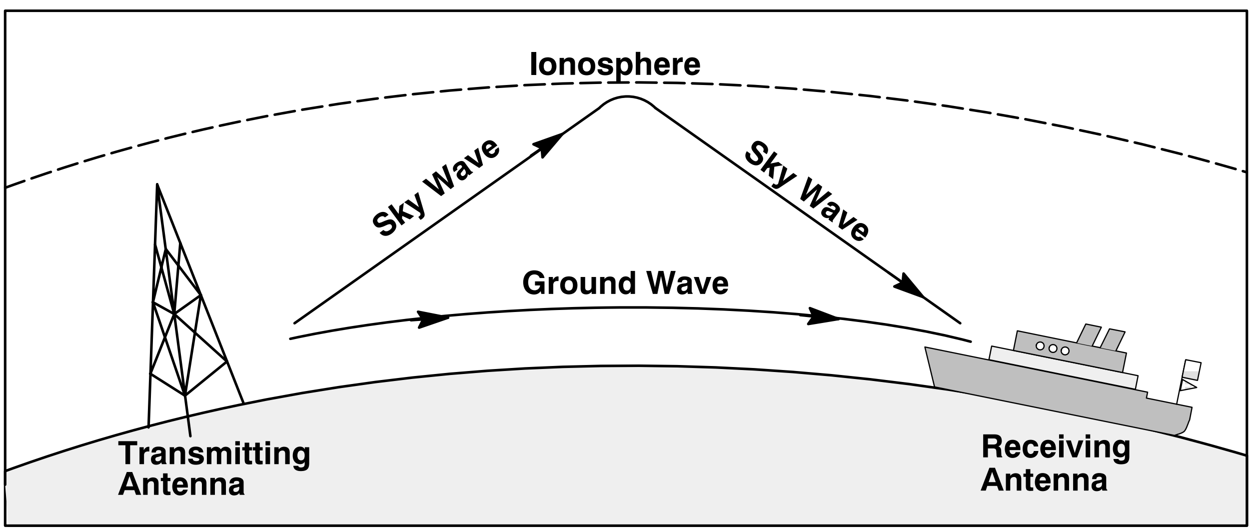

Figure 1.— *The paths taken by a radio wave transmitted by a terrestrial navigation system.*

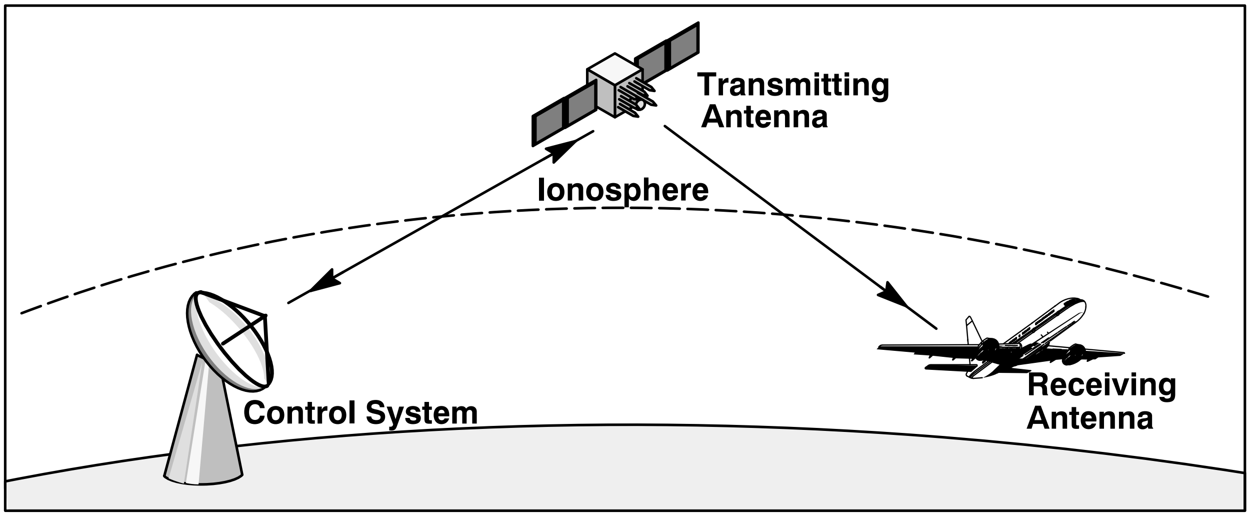

Figure 2.—*Ground stations monitor the information from the satellites and upload changes as needed to ensure that the navigation information is accurate.*

More recently, space-based systems—the Global Positioning System (GPS) and others—have become the pre-eminent methods of navigation (see Figure 2). Satellites afford greater coverage of the globe than do land-based systems; they provide a constant source of guidance for the longest terrestrial journey. When at least four satellites are in view, a user can obtain an accurate, three-dimensional position. At times when more than four satellites are visible from one location, the navigator enjoys an even greater level of confidence in the computed position (see Figure 3).

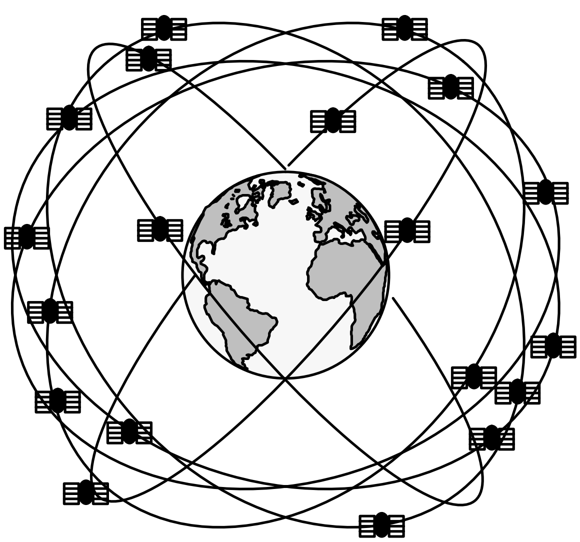

Figure 3. The constellation of navigation satellites assures that four satellites are always in view.

The thread common to both terrestrial and satellite-borne systems is the ionosphere; Omega navigation requires it, Loran tries to work around it, and GPS is hindered by it. Unlike the low-frequency radio transmissions used by terrestrial systems, GPS uses radio signals that pass through the ionosphere (see Figure 4). The ionosphere, lying above 50 km out to a few Earth radii, is neither homogeneous in structure nor constant over time. Solar and geomagnetic activity affect the character of the ionosphere and, consequently, the proper function of navigation systems. (Refer to Space Environment Topics SE-10 for more on radio-wave propagation.) Since both solar and geomagnetic activ-

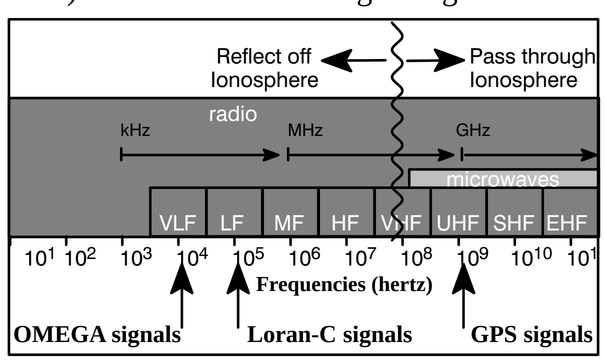

Figure 4. The frequencies of the most common navigation signals.

ity vary over the course of the 11-year solar cycle, the modern-day navigator will experience conditions in the solar maximum epoch different from those in the years near solar minimum. The specific circumstances (i.e., the system being used, the user's location, the phase of the solar cycle, the month of the year, and the time of day) will impact the accuracy of the location determined by the navigator.

Solar Flares

Solar flares, the impulsive release of large amounts of radiant energy, disturb the ionosphere on the sunlit side of Earth. These flares are usually associated with the strong magnetic fields that manifest themselves in sunspots, so their occurrence rate increases and decreases in step with the sunspot cycle (see Figure 5). Navigators find it more difficult to use Loran-C and Omega during daylight hours in the maximum phase of the solar cycle; conversely, fewer problems are experienced during solar minimum. These flare effects, which are due to solar x-rays, are not a problem for GPS users. GPS signals are generally immune to ionospheric changes in response to large infusions of solar x-rays.

Geomagnetic Storms

The geomagnetic field is affected by solar stimuli whose frequency and intensity differ according to the phase of the solar cycle. Geomagnetic storms usually result in ionospheric storms and, hence, they affect navigation systems. Unlike solar x-rays, which impact only the sunlit hemisphere of Earth, geomagnetic storms are ubiquitous. However, the ionospheric response to these storms is dependent on latitude; so conditions, nearer the equator or nearer the pole, vary for the navigator. Paradoxically, a quiet, undisturbed geomagnetic field does not necessarily dictate an undisturbed equatorial ionosphere; this underscores the great variability in the environment: a geomagnetic storm is sometimes a foe for a navigator and sometimes an ally.

GPS operations anywhere on Earth are affected by the changes in total electron content (TEC) of the ionosphere along the path to the satellite during large magnetic storms. Large increases and decreases in the bulk plasma TEC directly influence the accuracy of single-frequency GPS. Dual-frequency GPS receivers actually measure the effect of the ionosphere on the GPS signals and can better adjust to these difficult circumstances.

On a smaller scale, irregularities in TEC that produce scintillations occur in varying amounts, depending on latitude. For example, the equatorial region, (the latitude zone that spans 15-20 degrees either side of the magnetic equator) is the site of some of the greatest iono-

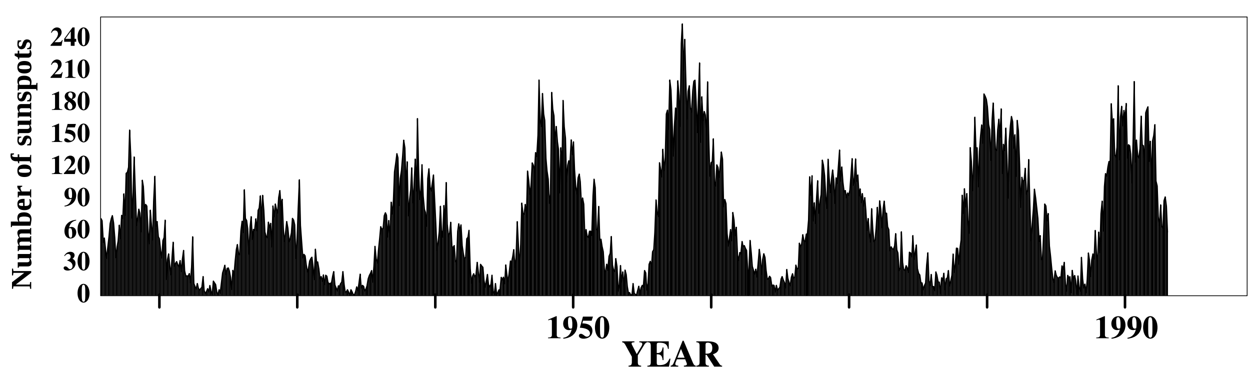

Figure 5.— *The sunspot cycle suggests the cyclical nature of the sun's activity. The cycle corresponds with some, but not all, types of disturbances to navigation systems.*

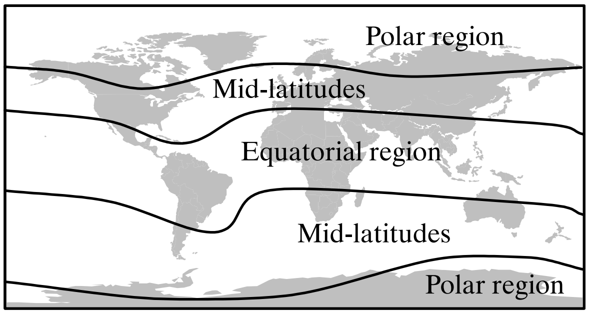

Figure 6.—Ionospheric regions of the world.

spheric irregularities, even when magnetic storms do not occur (see Figure 6). Seemingly unpredictable episodes of density enhancements in the upper ionosphere can occur in the evening hours there and can cause radio waves to be misdirected. These scintillations make GPS operations difficult, and they can affect both dual- and single-frequency GPS receivers.

Solar Energetic Particles

Occasionally, but more often during the years near solar maximum, the Sun ejects large quantities of energetic protons and electrons. These energetic particle events persist for a few days at a time; they can affect both ground-based and space-based systems, but in different ways. Loran-C and Omega signal propagation is degraded, especially at polar latitudes, due to the ionosphere's response to the addition of these solar particles (primarily protons). GPS and all other satellites must contend with the detrimental effects energetic particles have on the on-board systems.

Navigation has advanced dramatically from the days when the stars in the sky marked the way. Now, it is the behavior of our nearest star that tempers the function of navigation systems.

Systems affected by the space environment

Loran-C

Phase and amplitude shifts due to skywave interference at the limits of coverage area.

GPS

Carrier loss-of-lock due to ionospheric density fluctuations with solar or geomagnetic activity.

Omega

Phase anomalies due to varying ionospheric reflection heights, associated with solar or geomagnetic activity.

The Space Environment Services Center monitors and forecasts these phenomena:

Solar flares of sufficient energy to disrupt navigation systems,

Geomagnetic storms that may affect ionospheric conditions,

Solar proton events that can perturb the ionosphere locally and globally.

Written by Joe Kunches, 1995

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